Addendum to Report on The Economic Impact of the COVID-19 Pandemic: Quantifying the Damages to the Missouri Economy

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Executive Summary

The purpose of this addendum is to consider additional identification schemes directed at quantifying the role that PPE hoarding had on the Missouri economy. Here, identification is equivalent to more fully characterizing the mechanisms through which PPE hoarding affects economic activity. Economic damages, therefore, is computed to be the difference between economic activity without PPE hoarding and the *isolated* economic activity that is attributed to having occurred in a state of PPE hoarding. The economic damages are computed for both the overall Missouri economy and those suffered by the government of the State of Missouri.

The economic damages can be traced directly to sequestration and lockdown policies implemented at the Federal level. The links are characterized as follows: (i) PPE hoarding affects the infection rates; (ii) without PPE hoarding, infection rates would have been reduced; (iii) with lower infection rates, there would have been less need for sequestration and lockdown policies to be implemented; and (iv) with less restrictive sequestration and lockdown policies, the economic damages associated with production losses would have resulted in smaller economic damages.

The three cases are differentiated by different quantitative assumptions regarding the impacts on infection rates and the timing of sequestration and lockdown policies.

- For the contemporaneous economic damages, the cumulative sum of Missouri GDP losses is $24.01 billion during the period 2020 Q1 and 2023 Q2, but could be as low as $12.4 billion.
- For the future economic damages, the cumulative, discounted sum of GDP losses in Missouri are $480.24 billion between 2024 and 2051. If the infections are reduced at a slower rate, we find that total economic damages could be as low as $246.96 billion 2024 and 2051.
- By combining contemporaneous and future economic damages, the lost real GDP in Missouri could be as high as $492.64 billion or as low as $259.36 billion between 2020 and 2051.
- If we simply sum the loses, the maximum (undiscounted) economic damages equal $1,077.23 billion and the State of Missouri collects $33.39 billion less in taxes.
- For the State of Missouri, the discounted sum of net general revenue losses is projected to be as high as $15.27 billion and as low as $8.04 billion due to PPE hoarding.
- On the low end of the range of economic damages, consider the sum of economic damages without discounting. In this case, the total economic damages sum to $561.47 billion. For the State of Missouri, the sum of revenue collections is $17.41 billion less between 2020 and 2051.

In this addendum, I examine varying identification strategies aimed at quantifying the impact that PPE hoarding had on the Missouri economy. In other words, what are the economic damages to the State of Missouri's economy given the PPE hoarding claim in case no 1:20-cv-00099-SNLJ (hereafter the shorthand reference is the State of Missouri v. the People's Republic of China).

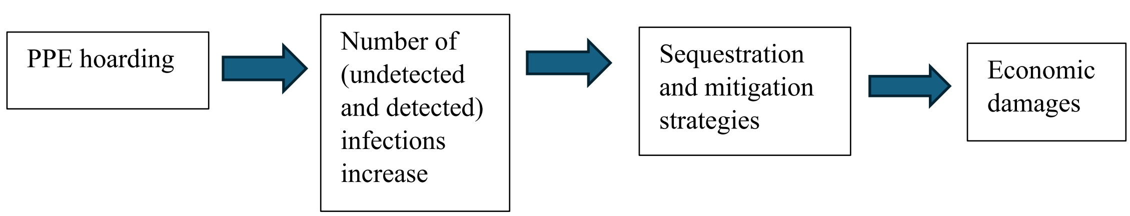
The question posed is as follows: assume that the People's Republic of China and their agencies acted in ways to reduce the flow of Personal Protection Equipment (PPE) to the United States, especially during the period beginning in March 2020. With PPE supply shortages, the number of infections rose, and economic damages were incurred. The specific question is: can one carefully identify the (marginal) quantitative impact that China's PPE supply hoarding had on any economic damages suffered by the Missouri economy and the State of Missouri?

This question begs a more thorough representation of the mechanism through which the cause (the purposeful hoarding of PPE equipment) affects the economic damages. I represent a causal chain in Figure 1.

Figure 1

A Representation of the Transmission Mechanism from

China's PPE Hoarding to Economic Damages suffered by Missouri



The transmission mechanism presented in Figure 1 is a model of the mechanism that leads from the disease through PPE hoarding to economic damages. By presenting Figure 1, the reader has a clearer vision of the process that led from the hoarding to the economic damages. As measured in the initial report, the economic-damage calculations focused on changes to the flow of production and human capital accumulation. These economic damages, therefore, were calculated as if the sequestration and mitigation strategies played the critical role in quantifying dollar values. The results of the calculations provided in

my previous expert report submitted in this case serve as an upper bound on the size of the economic damages suffered by the State of Missouri.[1]

With Figure 1, it is possible to examine the nature of the transmission process by breaking the process into its components. The first link is between the shortage of PPE and the number of infections. More precisely, our goal is to present quantitative evidence on the impact that PPE reductions had on the infection rate.

Efficacy of PPE units

There is evidence that PPE units are effective in reducing the spread of COVID 19. For example, Griswold, *et al.* conclude the following: "The use of PPE drastically reduces the risk of COVID-19 compared with no mask use in HCWs in the hospital setting. Respirators like N95 or equivalent provided more protection and were found to halve the risk of COVID-19 contagion in HCWs from moderate- and high-risk settings."[2] While the sample is limited to health-care workers, this is a good projection of how increases in the number of PPE units would have affected the infection rate. Indeed, Griswold *et al.'s* analysis provides a basis for calibrating the reduction in infections owing to an uninhibited supply of PPE. Based on the evidence in Griswold, *et al.*, we can establish that portion of the linkage between PPE and the number of infections. Note that the observed pattern without sufficient PPE units resulted in higher number of infections. Between February 2020 and June 19, 2020, the United States had 2,946,626 confirmed cases of COVID 19.

To get a sense of the quantitative impact, we specify a model of the infection level as a function of PPE units. With this model, we can then consider how changes in the quantity of PPE units would have affected the number of infections. Consider the following formula as a starting point for this calculation. Let $I^C = K(x) - 0.5\,P^C$ where I^C stands for the number of infections in the "control" setting, $K(x)$ stands for the number of infections as a function of x which is an $N \times 1$ vector of all the other variables that affect COVID 19 infections, and P^C stands for the number of PPE units in the control setting. The Congressional Research Service has indicated that 70 percent of PPE were imported from China, including U.S. companies producing there.[3] The first step is to get a sense of what the infections would have been

[1] Economic damages could also be computed as the loss of human capital, so that the number of infections leading to death would play the critical role in the calculations.
[2] See Griswold, Dylan P., BA, Andres Gempeler, MD, Angelos Kolias, MD, PhD, Peter J. Hutchison, MBBS, PhD, FRCS, and Anders M. Rubiano, Md, PhD, 2021, 'Personal protective equipment for reducing the risk of COVID-19 infection among health care workers involved in emergency trauma surgery during the pandemic: An umbrella review," *Journal of Trauma Acute Care Surgery*, 90(4), e72-e80.
[3] See Cecire, Michael H., Agata Bodie, Frank Gottron, Victoria Green, L. Elaine Halchin, Erica A. Lee, Andres, B. Schwarzenberg, Kavya Sakar, Michael, D. Sutherland, Karen M. Sutter, "COVID-19 and Domestic PPE Production

with a full supply of PPE. The experiment involves scaling up the number of PPE units based on the percentages produced in China and the U.S. To get the scaling factor, note that 70 percent of PPE units are produced in China. For a given P^C, with 30 percent of production available, we are interested in the number of PPE units with 70 percent of the production available. One way to scale up is to multiply the number of PPE units by the ratio of the two percentages; that is, multiply P^C by $0.7/_{0.3}$ to account for the additional production allowed from China.

Note that for the purposes of this experiment, the data on the number of PPE units is not observed. The goal is this segment is to get a formula that characterizes the relationship between the number of infections with full PPE supply and the number of infections with PPE hoarding. In other words, what is the *change* in infections for a given change in PPE units. Such a formula will help us understand the actual experiments presented later in the addendum. For example, let the control period represent what we observed during the period March 2020 through June 2020. Let $I^T = K(x) - 0.5 \times \left(0.7/_{0.3}\right) P^C$, where I^T denotes the number of infections when treated by an increase in the quantity of PPE units. Then, hold everything else constant and calculate

$$I^C - I^T = 0.65 \times P^C. \qquad (1)$$

Equation (1) specifies the difference in the number of infections as a function of the number of PPE units. In other words, the change in the number of infections is equal to the product of 0.65 and the number of PPE units in the observed setting. With the right-hand side of the equation as the product of two positive numbers, we know that the projected number of infections would decline with the additional PPE units released by China.

PPE units and the contact rate

Equation (1) extends the process described in study by Khan *et al*.[4] In their paper, the authors specify seven differential equations with seven different states that pertain to the epidemiological analysis of COVID-19. The seven states are: Susceptible, Undetected Infected, Detected Infected, Detected Recovered, Quarantined, Undetected Recovered/Dead, and Detected Dead. Thus, the seven differential equations, therefore, correspond to the instantaneous rates at which people move from one state to another. Equation (1) provides a rational for the contact rate to be dependent on the number of PPE units.

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and Distribution: Issues and Policy Options," Washington, D.C.: *Congressional Research Service,* December 7, 2020. The report can be found at https://crsreports.congress.gov/product/pdf/R/R46628 .

[4] See Khan, Z. S., F. Van Brussell and F. Hussain, (2020), "A predictive model for Covid-19 spread--with application to eight states and how to end the pandemic," *Epidemiology and Infection*, 148, e249, 1-13.

To understand the relationship between the contact rate and the number of PPE units, it is useful to provide a sketch of the mechanisms at work in the Khan *et al*. (hereafter SQUIDER) model. The incidence rate plays a central role, measuring the flow of people moving from the Susceptible state to the Undetected Infected rate. (Note that a fraction of those in the Undetected Infected state are identified and moved into the Detected Infected state.) The incidence rate depends on the contact rate. In the SQUIDER model, the contact rate depends on the number of contacts a person experiences in a day times the probability that a contact results in the disease transmitted from those in the Undetected Infected state to those in the Susceptible state. In the SQUIDER model, the contract rate is treated as a constant. The authors mention that the contact rate may be time varying. There are a set of experiments in which the contact rate is manually changed, with infection rates computed over time.

For much of the analysis, Khan *et al*. focus their energies on examining the pulse that describes moving people from either the Susceptible or Undetected Infected states into the Quarantined state. Our model shares the basic driving mechanism with the one presented in the SQUIDER model. Formally, Equation (6K) is written as:

$$\frac{dQ}{dt} \equiv \dot{Q} = q(t)\,(U + S) \qquad (6K)$$

where U is the fraction of people in the Undetected Infected State, S is fraction of people in the Susceptible state and $q(t)$ is the pulse that describes the rate at which are moved into the Quarantined state.[5] Equation (6K) says that the instantaneous rate of the fraction of people respond by moving into the Quarantined state. In other words, the Quarantined state (our Sequestration state in Figure 1) is an endogenous response to the number of people in the Susceptible and Undetected Infected states. The point is that Equation (6K) corresponds with the move from the left-middle box to the right-middle box in Figure 1.

There is one key difference between the description in Figure 1 and the SQUIDER model. The SQUIDER model allows for a feedback rule. With the pulse variable, $q(t)$, the fraction of people in Susceptible and Undetected Infected states move into the Quarantined state, resulting in an instantaneous response in the rate of the population's fraction being in the Susceptible and Undetected Infected states. Figure 1 does not characterize such a feedback rule. Rather than modelling the feedback rule, Figure 1 emphasizes the tole played by changes in the contact rate and how it creates economic damages.[6]

[5] The label 6K used to denote this equation is taken Khan, *et al*. and not an equation derived in this report.

[6] The absence of the feedback loop is important for assessing how the disease progressed over the entire period of infection. However, the period to which hoarding PPE is a short period covering most of the period from March 2020 to at least September 2020. Feedback loops are treated as they were not quantitatively important during this period.

So, what does our Equation (1) do? It provides a missing link in the SQUIDER model. In particular, Equation (1) specifies a theory that accounts for movements in the contact rate as a function of the number of PPE units. By establishing this link, we can use the experiments from the SQUIDER model that allows for changes in the contact rate. Once the contract rate is changes, the SQUIDER model will provide a dynamic response in infection rates; formally, the SQUIDER model quantifies the changes in the contact rate and, ultimately, the flow of people into the Quarantined state.

Contact rates and Sequestration/Lockdown

For Khan *et al*. data are used from eight states: Arizona, California, Florida, Illinois, Louisiana, New Jersey, New York, and Texas. Interestingly, the estimated contact rate lies in a narrow band between 0.733 and 0.764. We focus on the contact rate because that is the primary mechanism through which the projected impact of PPE hoarding is quantified on infection rates.

To begin, consider the experiments presented by Khan *et al*. regarding the percentage changes in the contact rate and the quantitative impact on the total number of current cases in Texas. Recall that the contract rate was roughly 0.75. Further, recall that the contract rate is the product of the average number of contacts a person has per day and the probability of transmitting Covid-19 when contacting a person in the Susceptible state. The contract rate is only number reported by Khan *et al*. that contributes to the incidence rate, which is the average, normalized new infections.

In Figure 5, Khan, *et al*. consider contact rates falling between 2.5 percentage points and 15 percentage points. The dynamic responses are different for the percentage-reductions in contact rates in terms of the number of total current cases. For Texas, the plot shows that the total current infected numbers from April 2020 to January 2021 under different percentage-reductions in contact rates. For reference, the actual data show that the total current infected cases peaked at roughly 14,000 in September 2020. This number is important as a gauge of the number of cases consistent with implementing sequestration and lockdowns. Figure 5 also shows that a 2.5 percentage point decrease in contact rate reduces the peak number of total current cases from roughly 14,000 to about 7,500. For the case with a five-percentage point decrease in the contact rate, the peak number of total current cases in Texas is slightly less than 4,000 cases. Lastly, Khan *et al*. consider a 15 percentage-point decline in the contact rate. In this experiment, the peak number of total current cases occurs in June 2020 and is projected to be just above 2,000 total current cases. The June 2020 peak also projects a sharp decline in total current cases, falling to near zero by September 2020.

Based on the projections generated by the SQUIDER model, it is reasonable to conclude that PPE hoarding played a quantitatively important role in the number of cases in United States. By holding the number of contacts constant, the probability of becoming infected could fall by as much as one-third with

sufficient PPE.[7] Even with the more conservative 15-percentage-point reduction in contact rate, we see that PPE would have immediately started to decline in the United States.

We start by computing the projected change in the contact rate for a full supply of PPE. We start with two facts: (i) 70 percent of the supply of PPE coming from China and (ii) PPE reducing infections by 50 percent. What we can infer from these two data points is that the incidence rate could have been as much as 35 percent lower if PPE hoarding had not occurred. The 35 percent represents the impact that PPE hoarding had on infections. We have computed the incidence rate. To make the comparison with the SQUIDER experiments, we need to isolate the contact rate. Note the incidence rate depends on the contact rate. The contact rate is takes into account the probability that person will contract COVID-19.

To illustrate, we know that in Missouri, the number of new cases started rising significantly after May 31, 2020. According to the data provided by the U.S. Department of Health and Human Services, there were 139 new cases on May 31, 2020. By August 6, 2020, the number of new cases rose to 3,429.[8] Suppose there was adequate PPE supplies. Further, suppose that the increase in the number of new cases was reduced by 35 percent with the full supply of PPE. Missouri's number of new cases would have risen from 139 in May 2020 to 2,278 in August 2020. In terms of infections per 100,000 population, the difference in the number of new cases on May 31, 2020, and on August 6, 2020, is projected to have declined from 52.7 per 100K to 35 per 100K. Thus, the incidence rate per 100K population would have declined by 17.7 cases.

To get the contact rate, we will use Equation (1). Suppose the probability of contracting the disease is, for example, four percent. We can infer the impact on the contact rate as follows: multiply 0.04 times 0.65, getting 0.026. The idea is that will a full set of PPE, the probability declines by approximately one third. By holding the number of contacts per day constant, which is computed to 18.75, the contract rate would have fallen from 0.75 to 0.49. With full PPE supply, the analysis predicts a 26-percentage-point reduction in the contact rate. Khan *et al.* do not consider such a large percentage-point decrease in the contact rate. For our purposes, we use the path projected for their experiment with a 15-percentage-point decline in the contract rate. The dynamic response is notable; the number of total current cases peaks in June 2020 and monotonically declines over the next year to nearly zero cases.

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[7] The contact rate is expressed as follows: $CR_t = N_t \times \pi_t$, where N is the number of persons per day and π is the probability of contracting COVID 19. The change in the contact rate is treated as a linear change in the probability. Let the change in the contract rate be, $CR_t = N_t \times \pi_t \times \omega$, where ω represents the percentage change in PPE supplies without hoarding. With $\omega = 0.65$, by holding the number of contacts per day constant, the contract rate is equal to 0.49. In short, for any admissible value for the probability of contracting the disease, the impact on the contract rate will be equal to 0.49.

[8] Data obtained from the interactive website maintained by the New York Times. See https://www.nytimes.com/interactive/2021/us/missouri-covid-cases.html .

For the sake of being conservative, we also consider the case in which the contact rate declines by 2.5 percentage points with a full supply of PPE. In this case, the total current cases are projected to follow a non-monotonical path after June 2020. In this conservative setting, the number of current cases rises between June 2020 and September 2020, peaking at roughly half the actual number of current cases. After September 2020, the number of total current cases declines steadily through January 2021, falling from 7,500 total current cases (in Texas) to roughly 4,000 total current cases. Note that the projected 4,000 total current cases are about 80 percent of the actual number of total current cases recorded during the September 2020 to January 2021 period.

Sequestration and Lockdown

The next step is to establish the link between infection rates and the sequestration and lockdown policies implemented at the national level. Missouri is effectively a small open economy within the United States. The operating hypothesis is that national policies have a large impact on the performance of the Missouri economy. Consequently, it is sequestration and lockdown policies at the national level that are relevant for considering how economic damages occurred in Missouri.

We can formalize this notion by starting with a characterization of the production of final goods and services in the State of Missouri. A production function describes how factor inputs, like labor and physical capital, are combined to produce final goods and services. It combines all the different goods and services into a single market basket consisting of a single good, we can write the production function as

$$Y_t = A_t F\left(K_t, N_t\right) \tag{2}$$

where Y stands for the value of this single good produced, A is total factor productivity, K is the quantity of physical capital used, and N is the quantity of labor employed.[9] The function $F(.,.)$ describes the process that combines labor and capital to produce final goods and services. The key thing to note is that increases in either factor, for example, translates into more final goods and services. Formally, the marginal product of each factor input is positive.

It is easy now to see how sequestration and lockdown policies affect economic activity. Once implemented, the two factor inputs—physical capital and labor—are reduced. Consequently, with reductions in factor inputs, the quantity of final goods and services declines.

Sequestration and lockdowns were implemented based on the projected increase in infections. If the number of infections could have been sharply reduced with adequate PPE, it seems reasonable to believe

[9] It is easy to think of physical capital as the buildings and equipment used in the production process.

that there would have been no need for sequestration and lockdowns. The direct challenge is to take the projected paths for the number of cases and make one more projection; specifically, what fraction of the sequestration and lockdown policies would have been implemented? The alternative challenge is to take into account how the *expectation of PPE hoarding* had on government policy. The links in Figure 1 can be made clear. With PPE hoarding, the number of cases increased, leading to stronger sequestration and lockdown policies being implemented, leading to reductions in final goods and services. This is the essence of the economic damages.

In this analysis, the identification problem is made more difficult by the fact that there is no counterfactual that would help us identify the incidence rate that would have triggered lockdown policies. Instead, what we have are values based on the SQUIDER model that helps measure the effect of changes in PPE units on the number of total cases. With reductions in the number of cases, we can identify values of sequestration/lockdown policy changes and then compute the path for the Missouri economy.

Evidence of Sequestration/Lockdown Implementations

Researchers at Oxford University constructed their "Stringency Index."[10] The purpose is to provide a quantitative measure of the degree to which governments imposed lockdown conditions on a country. Formally, the researchers constructed an index by country based on 23 policy indicators, such as school closures, travel restrictions, mask mandates, and vaccination policies. The Stringency Index takes on values between 0 and 100. There were different policies implemented at state and local levels. In terms of the economic damages, the key assumption is that Missouri is a small open economy trading with the rest of the United States and other countries. The intuition is that Missouri's economic outcomes are directly tied to changes in the major trading partners; that is, restrictions on the rest of the country will affect Missouri production outcomes. The Stringency Index for the United States corresponds to role that national sequestration and lockdown policies would have on the Missouri economy.

Figure 2 plots the Stringency Index for the United States between January 1, 2020, and December 31, 2022. The data show the Stringency Index rose to above 70 on March 21, 2020. The Index reading stayed above 50 until March 23, 2021. The dates are important because these coincide with the critical periods in economic damages occurred; notably, insofar as the Stringency Index rose above 70 coincides with when we observed sharp reductions Missouri's real GDP. Moreover, the reading above 50 coincides with a large portion of the Academic Year 2020-2021 being lost. The Stringency Index above 50, therefore,

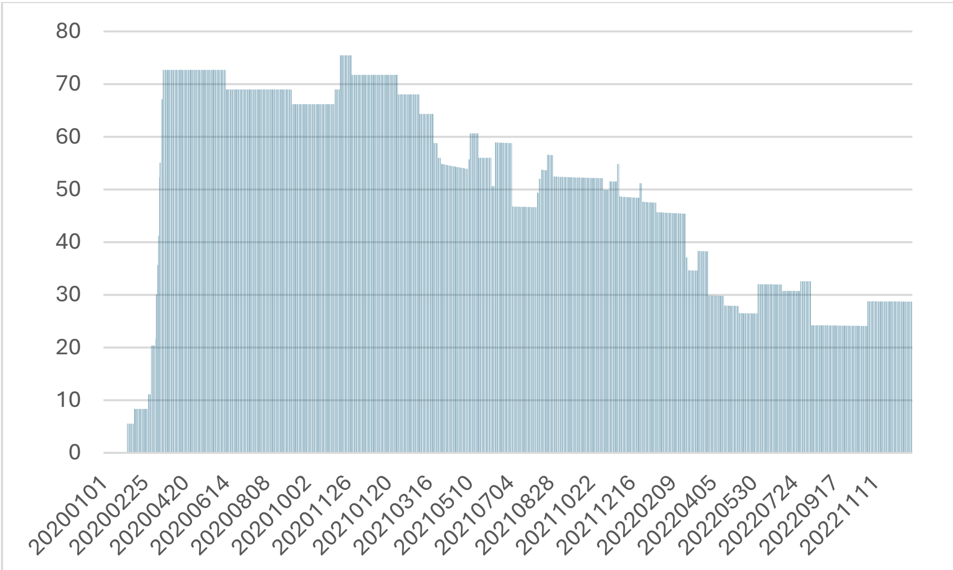
[10] Hale, Thomas, Noam Angrist, Rafael Goldszmidt, Beatriz Kira, Anna Petherick, Toby Phillips, Samuel Webster, Emily Cameron-Blake, Laura Hallas, Saptarshi Majumdar, and Helen Tatlow. (2021). "A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker)." Nature Human Behaviour. https://doi.org/10.1038/s41562-021-01079-8 .

could account for the damages to student learning that was reported in the persistent economic damages due to lost productivity growth.

Figure 2

Stringency Index, United States

January 1, 2020-December 31, 2022



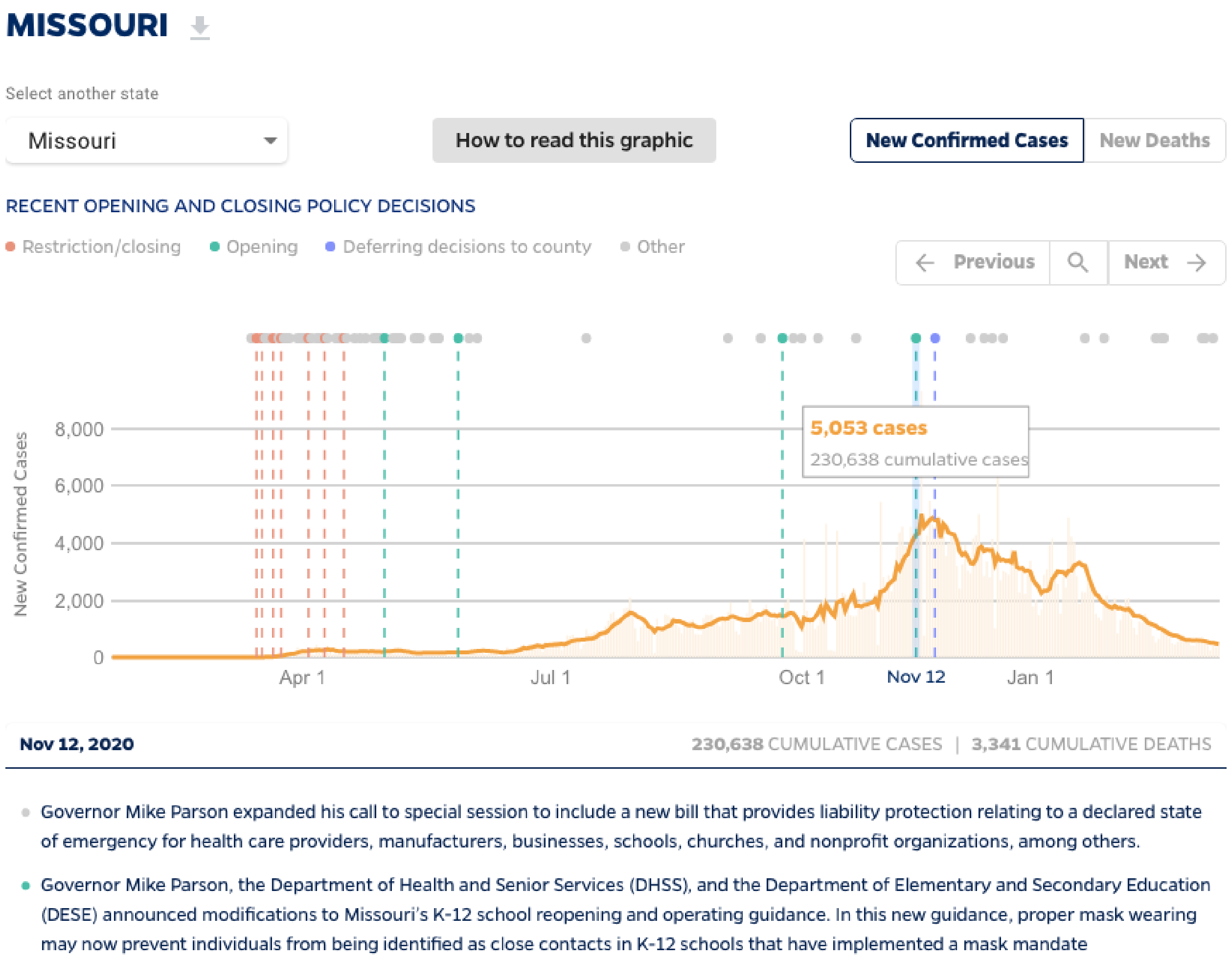
The value of the Stringency Index is that it provides a numerical measure of the degree to which sequestration and lockdown policies were implemented. Figure 2 gives us two additional pieces of information. First, we see the timing of when policies were implemented. By April 2020, the Stringency Index was above 70. Second, we see how sequestration and lockdown policies persisted with effectively discrete jumps as the Index declined over time. The discreteness actually allows us to identify when the Stringency Index corresponds to the sharpest declines in real GDP. Based on the evidence, Stringency Index values at or above 70 coincides with the largest declines in real GDP.

The timing raises additional questions. In particular, the Stringency Index increased sharply and read above 70 for the first time on March 20, 2020. The implication is that policymakers implemented sequestration and lockdown policies *before* we saw a large increase in the number of cases. Figure 3 shows the cases in Missouri increasing slowly. Such evidence is consistent with the notion that policymakers were projecting increases in the United States. For our purposes, the key question is how much did the knowledge of available PPE units affect the Stringency Index? With policymakers aware of

the low number of PPE units, did they more aggressively seek a substitute policy to quell the surge in the number of cases? Both lockdowns and PPEs are substitutes means of spreading the disease.

Figure 3

Number of COVID-19 Cases in Missouri



Source: Johns Hopkins Coronavirus Resource Center: https://coronavirus.jhu.edu/data

In the analysis below, two separate approaches will be examined.

To characterize the relationship between the Stringency Index and real GDP, start with the following expression:

$$Y_t^S = A_t^S F\left(K_t^S, N_t^S \right) \qquad (3)$$

Where Equation (3) represents different values for total factor productivity, physical capital, and labor dependent on the Stringency Index (captured by the superscript "S"). The values are inversely related to the Stringency Index; that is, as the Index increases, A_t^S, K_t^S, *and* N_t^S each decline. The implication is that the production of final goods and services decline. Moreover, the decline is nonlinear. Based on the evidence, it appears that the declines are most evidence for values of the Stringency Index at or above readings of 70. In other words, Equation (3) is consistent with the largest decline in real GDP when the Stringency Index is at above 70. Once the Stringency Index reads between 50 and 70, real GDP is adversely affected, but by much smaller losses. Indeed, in the 50-70 range, we observe real GDP bouncing back from its lows, though still below what it would have been without any sequestration or lockdown policies.

Calculations of economic damages

Next, we consider two alternative scenarios regarding the role that PPE supply without hoarding would have had on the Stringency Index. After this step, it is possible to apply calculations from the two scenarios and compute economic damages. This is the approach toward identifying the quantitative impact that China's PPE hoarding actions had on the Missouri economy by considering a range of outcomes.

Scenario 1:

The first scenario is quite straightforward. Consider a case in which there is no hoarding of PPE. Based on the reduction in the incidence rate associated with the PPE usage and the projected reduction from the SQUIDER model, levels would begin falling quickly with the peak occurring in June 2020. Between 2020:Q1 and 2020:Q2, Missouri's real GDP declined by $24.01 billion. This decline corresponds to when national stringency measures were implemented. There is a timing question. Why did the Stringency Index rise even though cases had not yet risen? One way to deal with the timing issue is to assume that sequestration and lockdown policies were implemented as if PPE hoarding was not a factor. Under this assumption, I recompute the lost real GDP between 2020:Q3 and 2023:Q4 when the pandemic ended. This new value is the value of lost real GDP associated with PPE hoarding. The value is $12.4 billion.

There is an alternative interpretation of movements in the Stringency Index. Suppose government decision makers were aware of the PPE hoarding and implemented policies conditional on this knowledge. Under this assumption, the PPE hoarding would have caused the immediate sequestration and lockdowns that account for the increase in the Stringency Index. Here, policymakers were aware of PPE shortages, knowing that PPE was relatively effective as a means of reducing the spread of COVID-19. Without necessary PPE, policymakers implemented sequestration and lockdown policies. In other words, the PPE hoarding caused resulted in policy actions that caused loss of Missouri real GDP during the 2020:Q1 and

2020:Q2 period. It follows from this logic that the economic damages caused by PPE hoarding was equal to $24.01 billion.

The second part of the economic damages owes to the lost schooling during academic year 2020-21. With a sharp decline in cases, it is reasonable to examine how much the lost productivity according to the Wharton Model. In other words, with a sharp reduction in the number of cases without PPE hoarding, K-12 education would not have been altered and the 0.4 years of education would not have been lost.

There are two ways to reports the economic damages between 2023 and 2051. By simply accumulating the losses in real GDP due to productivity losses, the projected damages are equal to $1,064.83 billion. In other words, real GDP is over $1 trillion lower over the next 28 years because of the PPE hoarding and its effects on worker productivity through the K-12 education disruptions. The second way is to covert future losses into their present dollar value. Here, discounting is the process that converts dollar amount lost in future years into what they are worth today. The formula is

$$PV_t = \sum_{t=2023}^{2051} \beta^{t-2023} ED_t \qquad (4)$$

where *PV* stands for the discounted sum, β is the discount rate, and *ED* stands for the economic damages in a given year. Throughout our analysis, we set the discount rate $\beta = 1/1.04$ to reflet the fact that the average return on a balanced portfolio is four percent. For Scenario 1, the discounted lost value of future real GDP in Missouri is $480.24 billion. The total economic damages would be $492.64 billion owing to PPE hoarding. Without discounting, the total economic damages are $1,077,24 billion. With Net General Revenues collected by the State of Missouri equal to 3.1 cents per dollar of GDP, the discounted sum of revenues losses is equal to $15.27 billion between 2020 and 2051. Without discounting the sum of revenue losses is equal to $33.39 billion.

Because the identification problem is so challenging, Scenario 2 is also presented below.

Scenario 2:

In this case, we consider a reduction in the contact rate to be 2.5 percentage points in contrast to the 25-percentage point reduction in Scenario 1. The key difference is that the model projects a decline in the peak number of new cases; with a 2.5 percentage point decrease in contact rate, peak number of total current cases from roughly 14,000 to about 7,500. The trajectory also matters. After peaking in September 2020, the number of cases begins to decline through January 2021. By 2021, the total number of current cases (in Texas) declines to roughly 4,000 from the 7,500 cases in the peak.

There is still no direct evidence that describes how quickly the sequestration and lockdown policies would be lifted as the number of cases occur. But, because sequestration and lockdown policies were partially implemented because of PPE hoarding, we would expect some decline in the Stringency Index without PPE hoarding. Indeed, we do observe Stringency Index readings fall to 50 by March 2021. In our analysis, the lost real GDP is the same as in Scenario 1 under the assumption that PPE hoarding did not account for the immediate sequestration and lockdowns. Specifically, between 2020:Q3 and 2023:Q2, Missouri's real GDP cumulative loss was $12.4 billion due to PPE hoarding. In terms of the productivity loss, the reduction in contact rate reduces cases such that the school year loss is 0.2 due to PPE hoarding compared with the actual 0.4 school-year loss projected with the actual data. The discounted sum of Missouri's real GDP losses due to productivity losses is equal to $246.96 billion. Thus, the discounted sum of total economic damages, including the lost GDP equal to $12.4 billion, is equal to $259.36 billion. Without discounting, the economic damages total $561.47 billion. For the State of Missouri, the discounted sum of net general revenue collected is projected to be $8.04 billion. Without discounting, the sum of revenue collections is $17.41 billion less than would have been collected without China hoarding PPE.

Summary

How much did PPE hoarding damage the Missouri economy? Three different values are presented. The upper bound is measured as if the PPE hoarding induced policymakers to implement sequestration and lockdown policies that resulting in economic damages to the State of Missouri. The dollar value of economic damages is calculated to be $503,446,370,000 in terms of reduction of Missouri's real GDP. Net general revenue collections are also affected. The discounted sum of lost state revenue collections is $15.61 billion.

An intermediate setting treats the initial sequestration and lockdown policies as independent of PPE hoarding. The dollar value of economic damages is equal to $492.64 billion in terms of lost Missouri real GDP. In this setting, the discounted sum of net general revenues is equal to $15.27 billion lost by the State of Missouri. If we simply sum the loses, the (undiscounted) economic damages equal $1,077.23 billion and the State of Missouri collects $33.39 billion less in taxes.

Lastly, we consider a weaker response in terms of PPE hoarding effect on the number of cases. There is a reduction in the peak number of cases and the decline in cases occurs earlier than we actually observed. Under this assumption, the discounted sum of economic damages is equal to $259.36 billion in terms of reduced levels of real GDP. The discounted sum of net general revenues is equal to $8.04 billion lost by the State of Missouri. Without discounting, the total economic damages sum to $561.47 billion. For the State of Missouri, the sum of revenue collections is $17.41 billion less between 2020 and 2051.